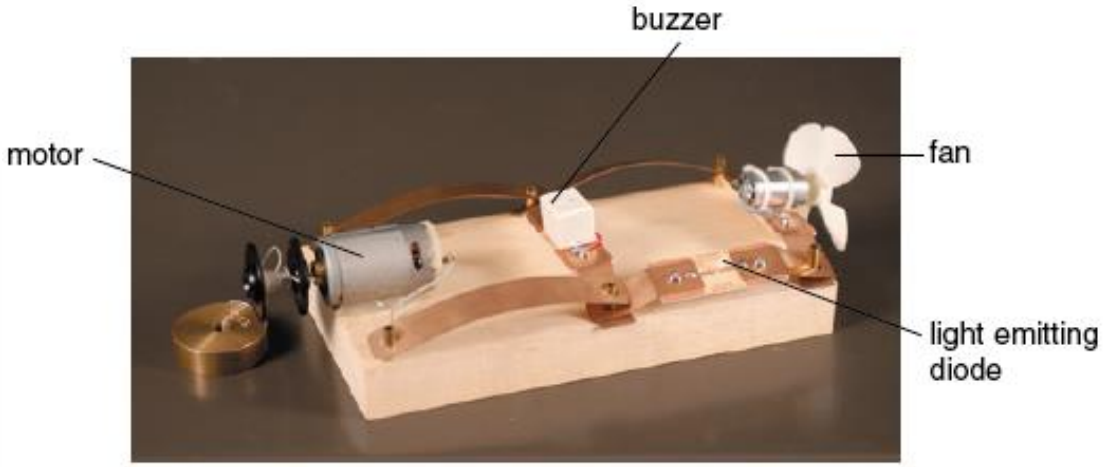
5.2 Generators and other applications of electromagnetic induction

Reverse a motor

Dismount a battery-powered handy fan.
Reconnect the motor to the circuit shown:



Turn the axis of motor rapidly. What happens?

The bulb lights up, the buzzer sounds and the fan turns on.

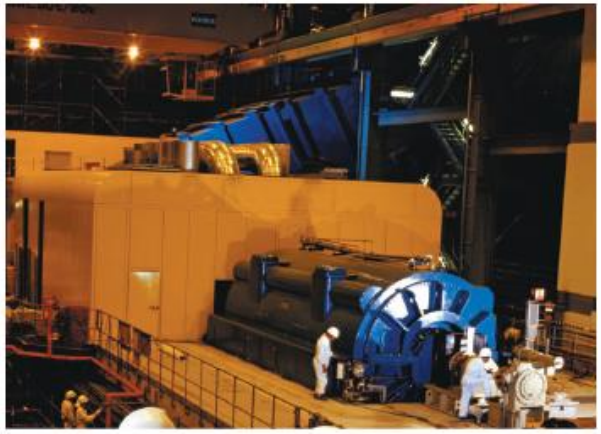
Video **5.5 Motor dynamo unit**

5.2 Generators and other applications of electromagnetic induction

Generators / dynamos

Examples: supplies mains electricity to homes, offices and factories from power stations

provides current to bicycle lights



Video 5.6 Shake-shake torch

5.2 Generators and other applications of electromagnetic induction

Generators / dynamos

- Use electromagnetic induction
- Based on the principle that current can be induced in a coil made to rotate in B-field
- convert other forms of energy into electrical energy

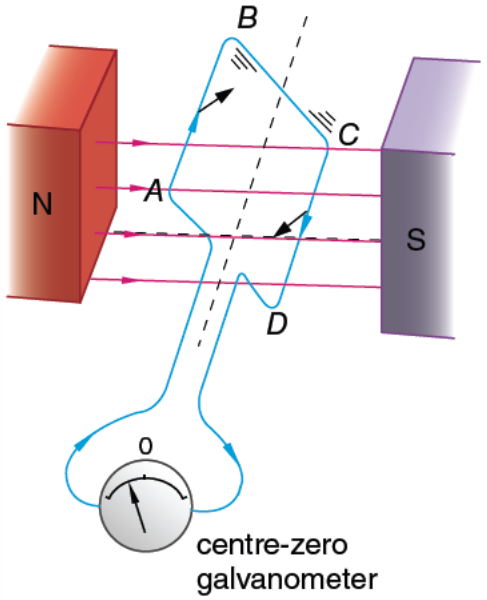
1 Generators

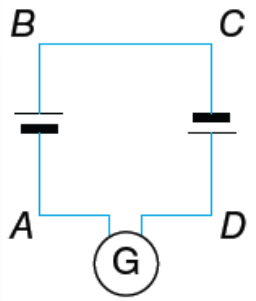
a Induced e.m.f and current in a rotating coil

When the coil is rotated, *AB* moves upwards and *CD* downwards through the B-field.

⇒ E.m.f. is induced across *AB* and *CD* as if there were two cells in series.

Combined induced e.m.f. drives a current to flow through circuit.





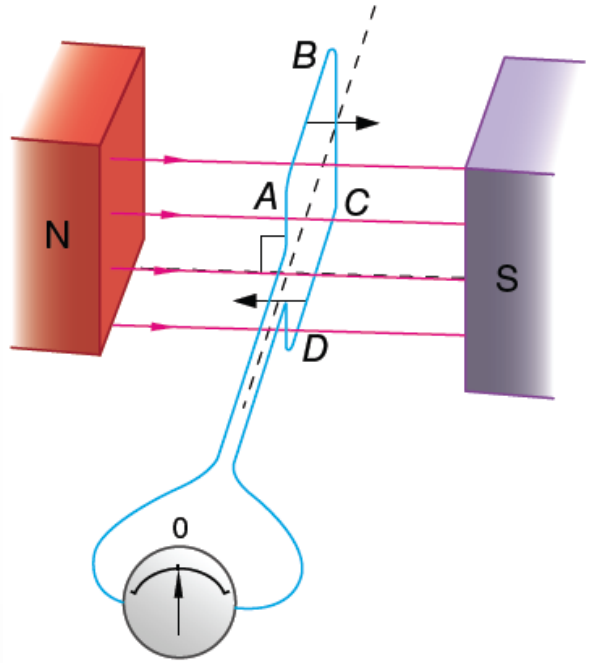
a Induced e.m.f and current in a rotating coil

The coil is a quarter of a turn from horizontal position, passing through the vertical position:

AB and *CD* are now moving parallel to the B-field momentarily.

$\Rightarrow$ no field lines are cut

$\therefore$ induced e.m.f. and current drop to zero.

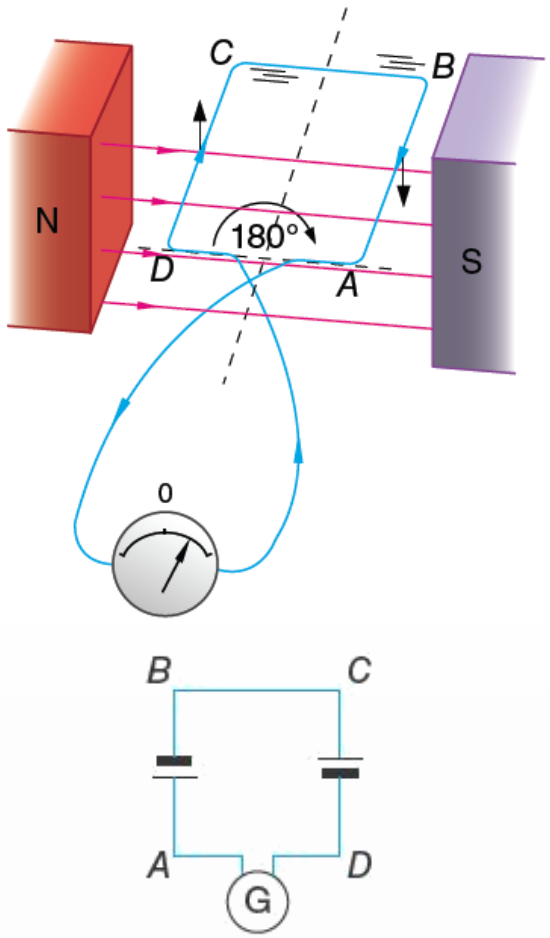


a Induced e.m.f and current in a rotating coil

The coil has completed half a turn:

An induced current flows but in an opposite direction.

$\because$ *AB* and *CD* are now moving downwards and upwards respectively.



a Induced e.m.f and current in a rotating coil

The coil has completed three quarters of turn:

- Vertical again.
- Induced current drops to zero.

The coil completes one turn:

- The situation repeats.
- The current continue to flow back and forth.
- Continuous supply of alternating current.

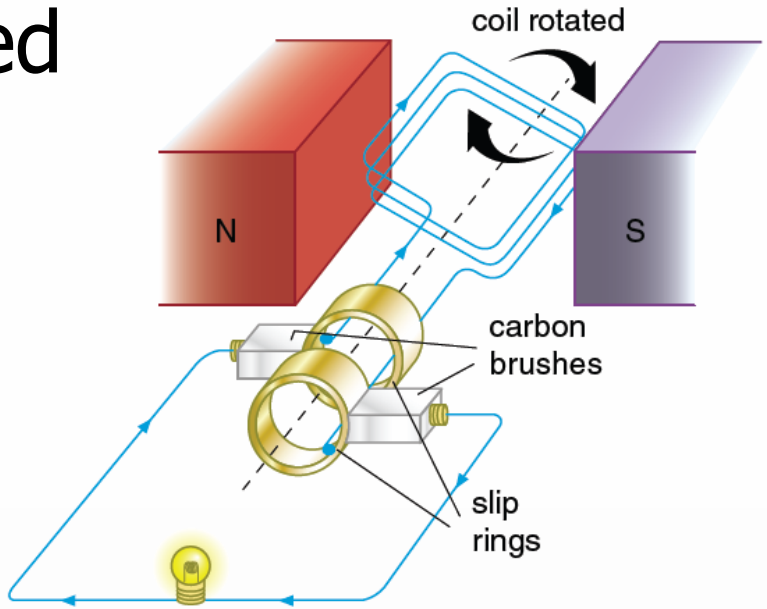
Simulation **5.2 Induced current in a rotating coil**

1 Generators

b Simple a.c. generator

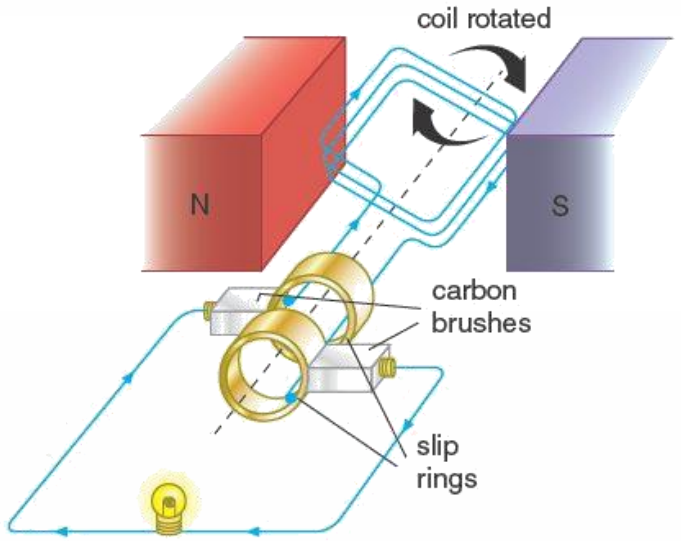
A simple **a.c. generator** / **alternator**:

- consists of a coil mounted on an axle between the poles of a magnet.
- ends of the coil fixed to two copper **slip rings**
  $\Rightarrow$ rotate with the coil



b Simple a.c. generator

- two **carbon brushes** press against the slip rings connecting them to the outside circuit.



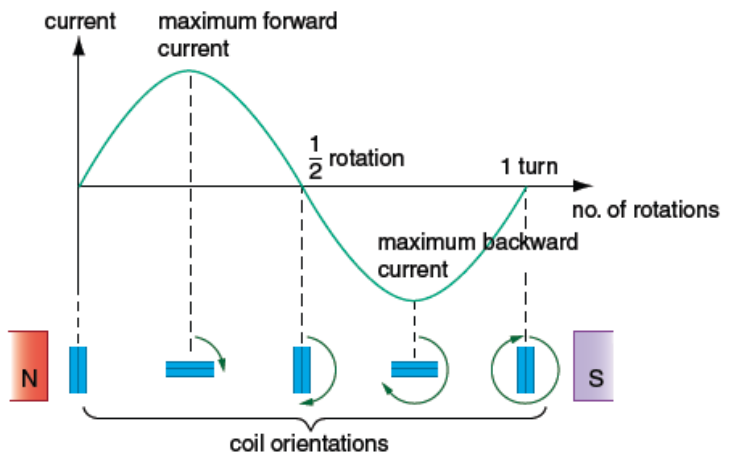
When the coil is rotated

$\Rightarrow$ alternating e.m.f. is induced

$\Rightarrow$ a.c. flows through the circuit

b Simple a.c. generator

A graph showing how the current varies during one complete rotation of the coil:



The current is

- the greatest when the coil is horizontal
  (∵ cutting through the field lines most rapidly)
- zero when the coil is vertical
  (∵ the rate of cutting field lines = 0)
- of the same frequency as the rotation of coil

Simulation **5.3 Simple a.c. generator**

b Simple a.c. generator

Induced e.m.f. and current ↑ when

- using a stronger magnet
- ↑ the number of turns in the coil
- ↑ the area of the coil (within B-field)
- winding the coil on a soft-iron core
- rotating the coil at a higher speed (i.e. higher frequency)

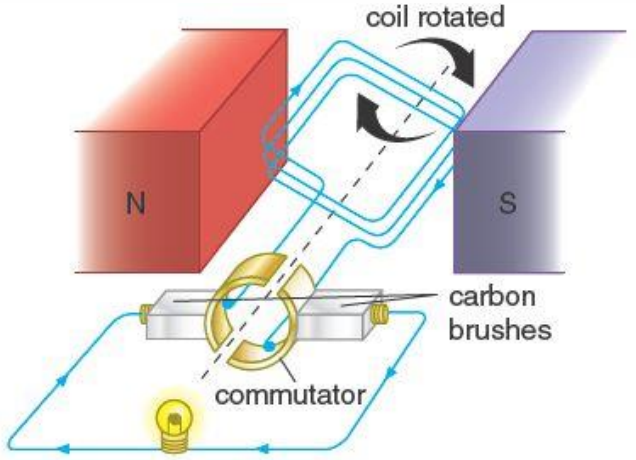
Example 9 **Current of an a.c. generator**

1 Generators

c Simple d.c. generator

Replace slip rings with a commutator
then a.c. generator → **d.c. generator**

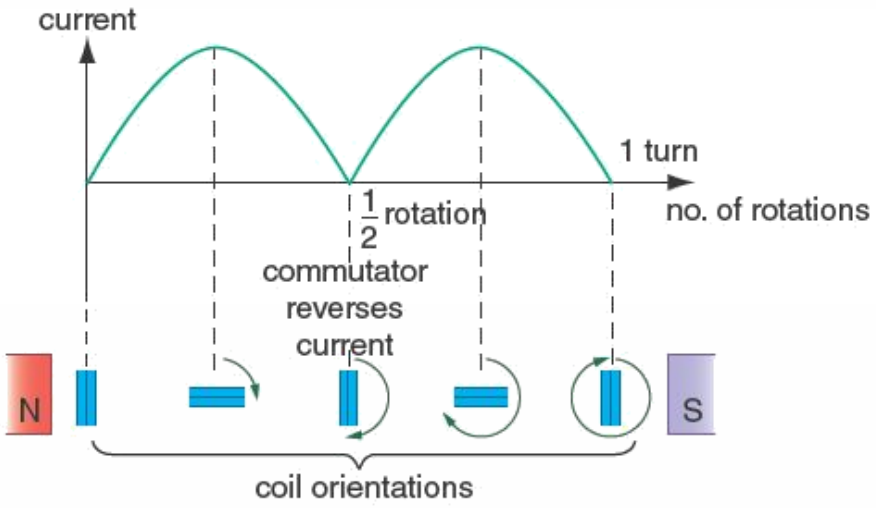
When the coil passes
through the vertical,
the commutator reverses
the connections of coil.



⇒ current in the outside
circuit always flows in the same direction.

c Simple d.c. generator

How the current varies during one complete rotation of the coil:



The current varies in size but its direction does not change.

$\Rightarrow$ direct current

Simulation **5.4 Simple d.c. generator**

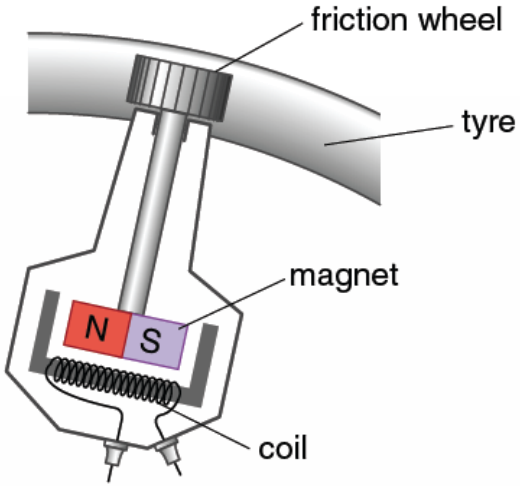
1 Generators

d Practical generators

i Bicycle dynamos

Bicycle dynamo has

- a fixed coil
- a rotating permanent magnet

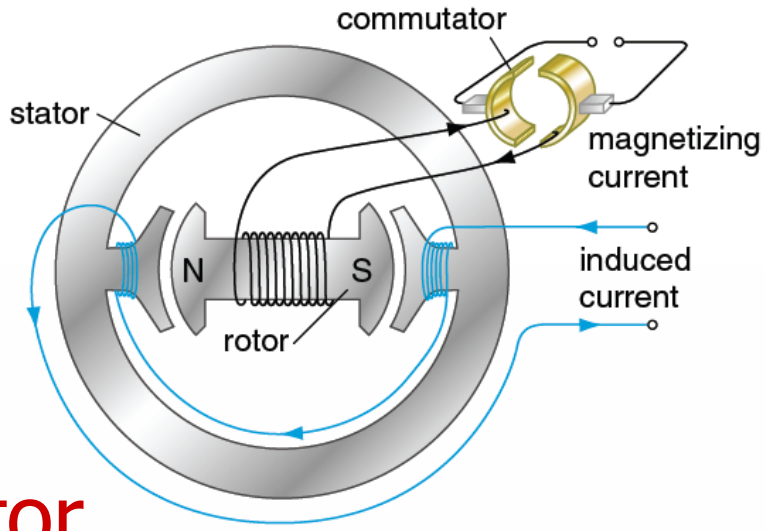


$\Rightarrow$ avoids the circuit from making connection via a moving contact

Rotation of magnet produces an induced a.c. to light up the lamp.

d Practical generators

ii Alternators



The practical a.c. generator generally has a rotating electromagnet and fixed coils.

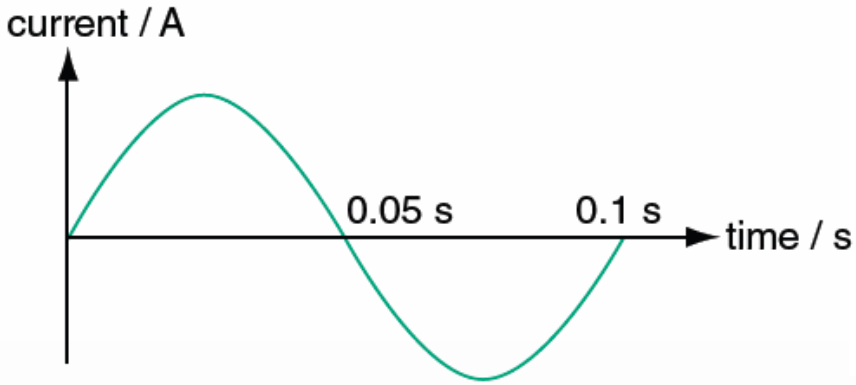
It is also called an alternator.

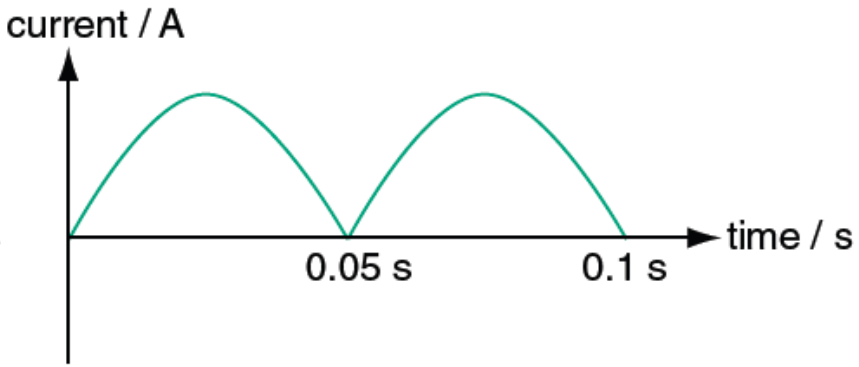
Huge alternators in power stations:

- generates electricity
- usually driven by steam turbine
- powered by fossil fuel or a nuclear reactor

Check-point 3 – Q1

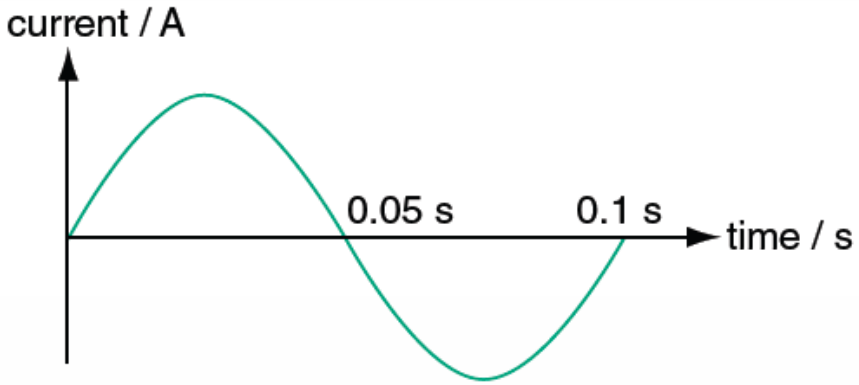
What are the turning frequencies of the coils of the a.c. generator and the d.c. generator?





Check-point 3 – Q1

The current from an a.c. generator changes sign for every ___half___ revolution(s).

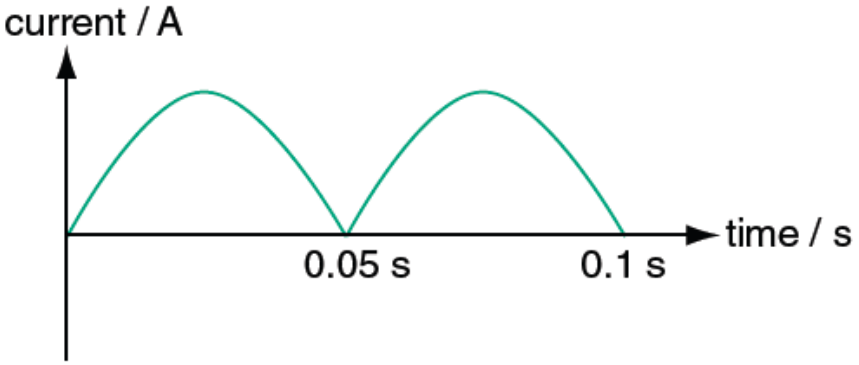


Therefore, the coil of the a.c. generator takes ___0.1___ s to complete one revolution.

By $f = \frac{1}{T}$, the rotation frequency of the coil of the a.c. generator is ___10___ Hz.

Check-point 3 – Q1

The current from a d.c. generator has two peaks in ___one___ revolution(s).



Therefore, the coil of the d.c. generator takes ___0.1___ s to complete one revolution.

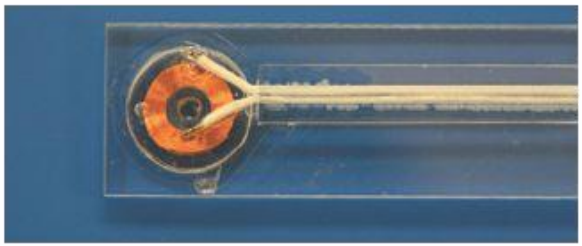
By $f = \frac{1}{T}$, the turning frequency of the coil of the d.c. generator is ___10___ Hz.

2 Search coils

Search coil:

- makes use of electromagnetic induction to measure varying B-fields

- consists of a circular coil with about 5000 turns and an area of about 10^{-4} m^2 (1 cm^2)



When the search coil is inside a changing magnetic field $B \perp$ the coil, an e.m.f. will be induced across the ends.

2 Search coils

Area of the coil is constant

$\Rightarrow$ magnitude of the induced e.m.f. $\propto$ rate of change of the magnetic field B

$$\varepsilon = -N\frac{\Delta\Phi}{\Delta t} = -NA\frac{\Delta B}{\Delta t}$$

If a B-field (varies with time) is measured by a search coil, the induced e.m.f. will also vary accordingly.

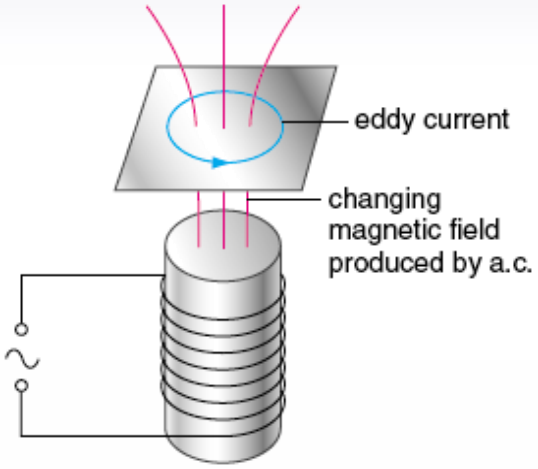
Expt 5d **Measuring magnetic field using a search coil**

3 Eddy currents

Expt 5e **Eddy current**

3 Eddy currents

When a piece of metal moves in a B-field, or when it is placed in a changing B-field, induced e.m.f. will be produced.



$\Rightarrow$ Induced currents (**eddy currents**) circulates within the body of metal.

By Lenz's law, induced current flows such that the B-field it produces opposes the change which started it.

$\therefore$ The ring jumps and the plate brakes in Expt 5e.

3 Eddy currents

Eddy current follows low resistance path

$\Rightarrow$ may be large even if induced e.m.f. is small.

Eddy currents can produce heating and magnetic effects

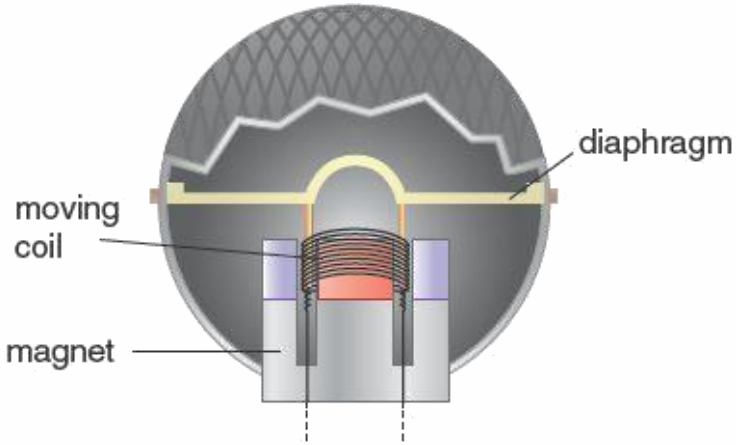
$\Rightarrow$ can be useful but sometimes undesirable

Example 10 **Jumping ring and metal plate pendulum**

4 Applications

a Moving-coil microphones

A moving-coil microphone consists of a small coil attached to a diaphragm:



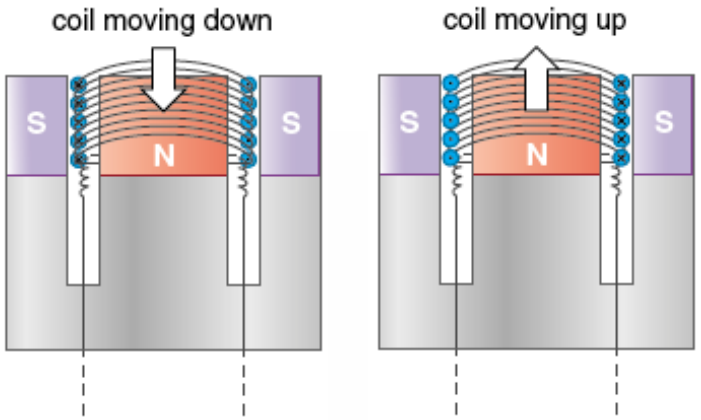
The coil can move up or down inside a cylindrical magnet.

a Moving-coil microphones

Speak into the microphone

⇒ the diaphragm vibrates

⇒ the coil moves up and down between the poles of magnet



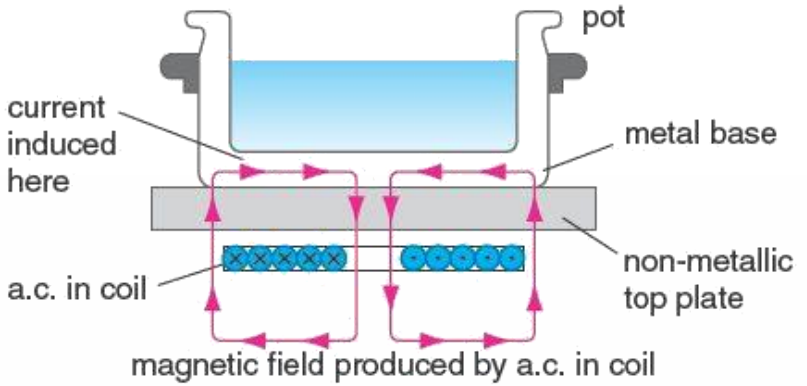
⇒ a.c. induced in the coil

The induced a.c. varies with frequency and amplitude of sound waves, and can be amplified and converted back to sound using a loudspeaker.

4 Applications

b Induction cookers

The Induction cooker uses coils of wires with high frequency a.c.



$\Rightarrow$ fast changing B-field

$\Rightarrow$ induces large currents in metal cooking pot

The pot gets hot due to the heating effect of currents and cooks the food.

Video **5.9 Induction cooker**

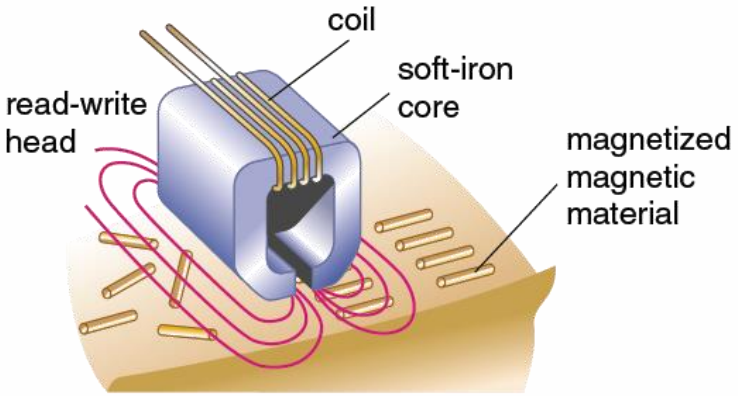
4 Applications

c Hard disks

The hard disk consists of several rotating disks called platters.

Each platter is coated with a thin layer of fine grains of magnetic material

$\Rightarrow$ like tiny magnets

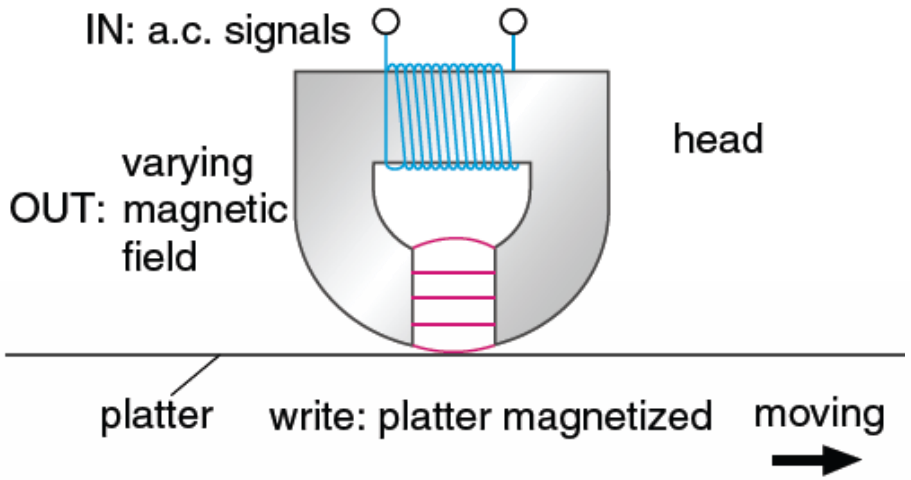


The read-write head (1 head per platter face) is tiny soft-iron core with a coil wound round it.

c Hard disks

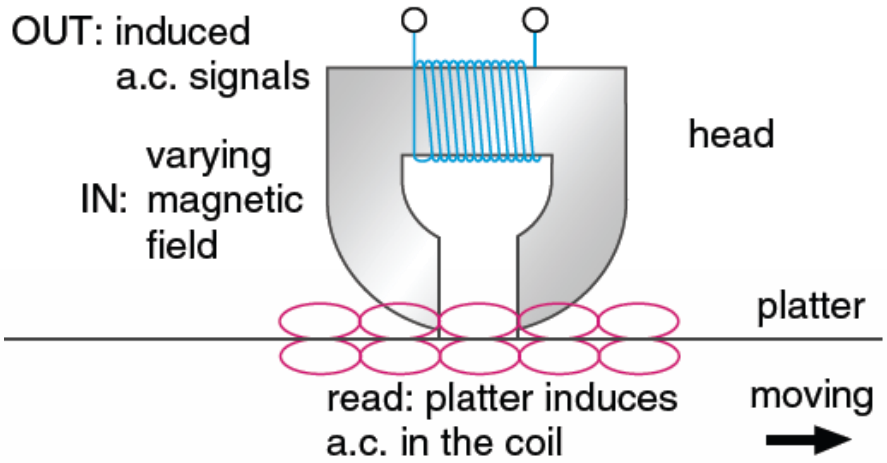
'Write' Information:

- convert information into a.c. signals
- magnetizes and rearranges the grains on platter in a certain pattern
- a magnetic 'copy' of the information



c Hard disks

'Read' Information:



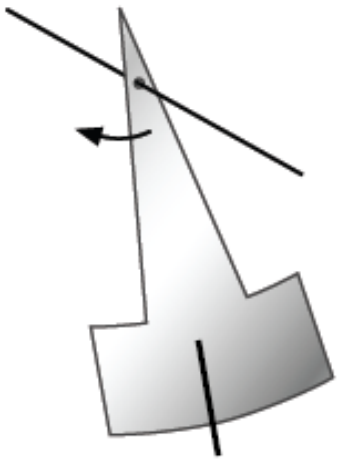
- B-field of grains induces a certain a.c. in the head
- a.c. signals are converted back to information
- hard disks can be found in video recorders, camcorders, etc.

Check-point 4 – Q1

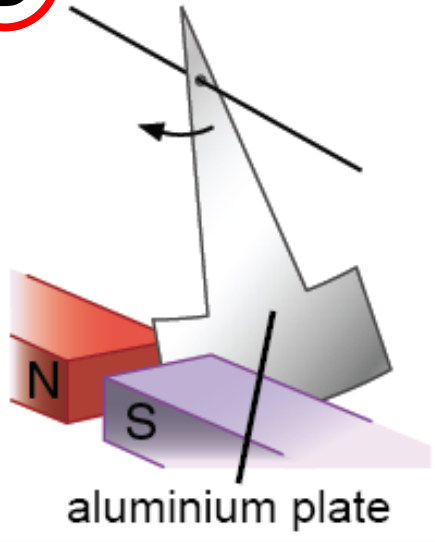
4 plates (same dimensions) are pivoted freely, pulled sideways to the same height and then released at the same instant.

Which of them would come to rest first?

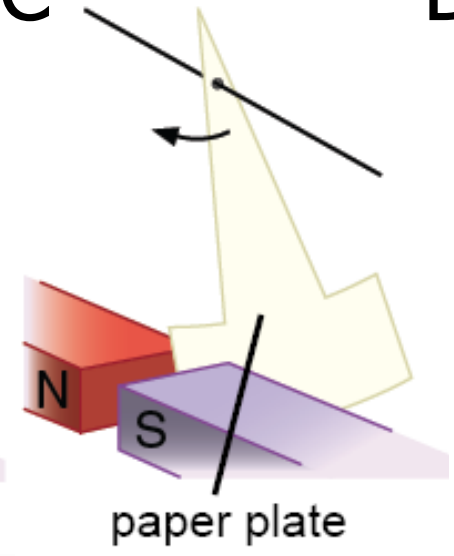
A



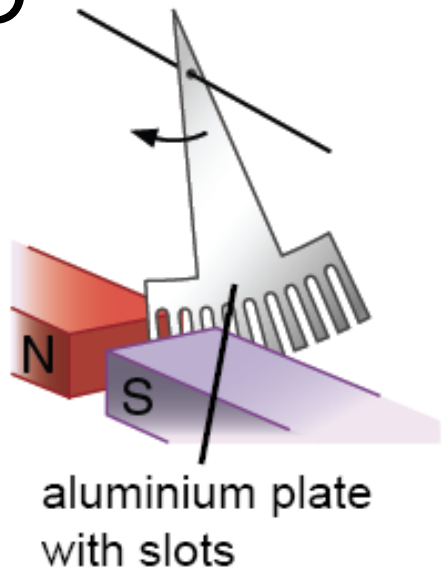
B



C

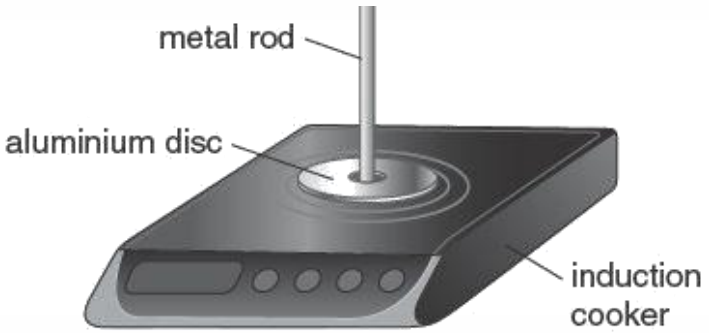


D



Check-point 4 – Q2

An aluminium disc is placed above an induction cooker and the cooker is then switched on.



What would happen?

(a) The disc would get hot. (Yes / No)

(b) The disc would be repelled upwards (Yes / No)

and then drops back. (Yes / No)

Check-point 4 – Q3

We usually use a search coil to measure

(constant / varying) magnetic field and

use a hall probe to measure

(constant / varying) magnetic field.

The End